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AN INVESTIGATION INTO THE RESISTANCE OF DISPLACEMENT TRIMARAN:A COMPARATIVE ANALYSIS BETWEEN EXPERIMENTAL AND CFD APPROACHES

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ABSTRACT

A displacement trimaran has several resistance components. The breakdown of these resistance components were experimentally studied by, the towing tank method. In addition, the phenomenon was also numerically studied by applying computational fluid dynamics (CFD). A typical trimaran model comprises of one main hull, which is 1.2-m long, and two symmetric side hulls, which are about 0.5-m long. The model was tested at various configurations, between Froude numbers 0.15 and 0.27, as well as at various lateral spacings (S/L) between 0.2 and 0.5. Experimentally, the model was examined with an ITS towing tank. For the CFD investigation, ANSYS-CFX was used, which is a commercial code. Each part of the trimaran hulls were tested, both experimentally and numerically. Such an individual examination, helped to elucidate on the interference phenomena between the hulls. A clear observation was noted using these methods. However, both methods helped to arrive at the same conclusion. The results demonstrated that, the wider the hull separation, the smaller the interference between the hulls. Furthermore, the wide separation (S/L=0.5) was an indication for 'no interference' between the hulls. This can be so assumed because, the overall result was comparably similar with the individual test of each hull, when interference was neglected, analyzing the obtained data comparatively with published data, which also suggests similar conclusions.

KEYWORDS: CFD, Interference, Resistance, Separation, Trimaran, Tank Test

INTRODUCTION

Over the last 40 years, vessels are increasingly being used to transport cargo and passengers. This means of transport, primarily uses less energy and has, therefore considered profitable. To improve the efficiency of the various designs, for hull form and its configuration have been proposed and developed. Some of the most notable hull types developed include, the the mono- and multihull types of vessel. The use of multihulls, such as in catamaran and trimaran, has received more popularity. This is mainly because of its better transverse stability. In addition, multihull provides wider deck, in comparison to the monohulls. Such a conclusion can be drawn, from the studies of Seif (2004) and Zouridakis (2005). Multihulls also have various other characteristic features, such as unique resistance, making them receive significant attention. Studies by Turner and Taplin (1968) have described in detail, the powering of large size catamarans. This was followed by Baba (1969), who explained the breakdown of resistance into its components. Pien (1976), Miyazawa (1979), Liu and Wang (1979), proposed methods to estimate the resistance interference of a catamaran. This was further studied by Insel and Molland (1992), who suggested explanations for the breakdown of catamaran resistance and proposed a mathematical formulation, to predict its resistance. Utama (1999), estimated the catamaran's viscous resistance using experimental and computational fluid dynamics (CFD) approaches. Utama et al (2008), proposed methods to estimate the resistance in a river catamaran and trimaran.

Trimaran is a multihull vessel. It has one main hull, which is placed inside, and two side hulls, which are placed at a lower height in comparison to the main hull. Results from studies suggest that, the trimaran can offer lower resistance at higher speeds, compared to monohulls (Maynard et al, 2008) and even to catamaran (Murdijanto et al, 2011). Pei-yong et al (2002), studies the trimaran to determine its wave-making resistance and wave resistance interference. They studied these variables, both experimentally and numerically. Muscat-Fenech and La Rosa (2014), examined the resistance of trimaran at various configurations of separation and draught. Both these studies rendered interesting discoveries, related to wave resistance and wave resistance intereference.

Resistance of Monohull

Ship resistance using a model has been suggested by various authors. However, the pioneer of this work is William Froude. The models used for the predictions are relatively much smaller than the real ship (Date and Turnock, 1999). Froude (1868) proposed that, the total ship resistance involves two separate resistances: frictional resistance and residuary resistance, which is dominated by wave resistance. Froude's expression is formulated as:

$$C_T = C_F + C_R \tag{1}$$

where C_T is the total resistance coefficient, C_F is the frictional resistance coefficient, and C_R is the residuary resistance coefficient.

The model proposed by William Froude, was further improved by Hughes (1954) and Granville (1956). They introduced the form factor, which helped to consider three-dimensional effect of the hull form. The total resistance was, thereafter, categorized into 3 (three) main components: *frictional resistance*, which is a tangential force formed by a reaction between the molecules of water and the skin hull of ship, and later known as resistance of surface area with comparable area and length with the ship model; form or pressure resistance, which results because of the shape of object and depends on the longitudinal section of the body and part of its component, and is popularly known as form factor (1+k); and wave resistance, which is a form of drag that has impact on surface watercraft, such as boats and ships, and reflects the energy required to push the water out of the way of the hull and helps in producing energy to create waves.

Mathematically, they are represented as follows:

$$C_T = (1 + k)C_F + C_W = C_V + C_W \tag{2}$$

Where C_W is the wave resistance coefficient, (1+k) is the form factor and (1+ k*)* C_F is the viscous resistance coefficient, which is later expressed as *(1+*C_V*)*.

The value of C_F may be estimated using ITTC-1957 correlation line as follows:

$$C_F = \frac{0.075}{(\log(\mathrm{Re}) - 2)^2} \tag{3}$$

Later, the international standard was set by ITTC (1978) in *"1978 Performance Prediction Method for Simple Single Screw Ships"*. This title categorized the total ship resistance into 2 (two) main components, based on practical knowledge. They considered the resistances as viscous resistance, as a function of Reynolds (Re) number and wave resistance, as a function of Froude number (Fr). The correlation between the 2 (two) components are formulated as follows:

$$R_{T\,(Fr,\,Re)} = R_{W\,(Fr)} + R_{V\,(Re)} = R_{W\,(Fr)} + (1+k)_{(Fr)}\,R_{F\,(Re)} \tag{4}$$

Resistance of Trimaran

The total resistance of a trimaran can be calculated using individual resistances of each hull, that is, the mainhull and sidehulls. However, it was noted that the combined resistance was higher than the individual resistances. The difference was suggested to be because of resistance interference or interaction. Currently, no formulas are available to calculate the total resistance and its interference; however, simple formulation proposed by Pien (1976) and Jamaluddin (2012) may be used, and it is expressed as follows:

$$IF = \frac{R_{T2}}{R_{T1}} \tag{5}$$

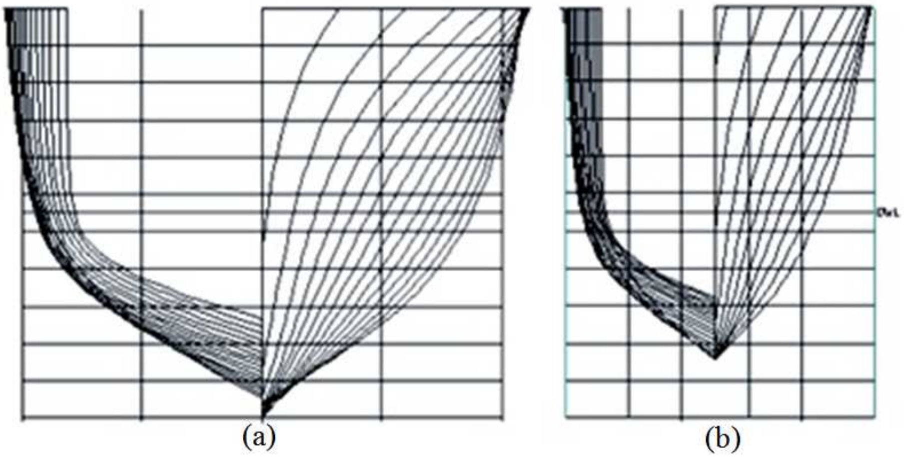
Where IF is the interference factor, R_{T2} is the total resistance of trimaran configuration, and R_{T1} is the total resistance of individual hull forming a catamaran.

METHODOLOGY

Investigation was performed by experimental and numerical analyses. The experimental study was performed with a ship model and tested at ITS towing tank. In contrast, CFD investigation was counducted using a commercial CFD codel called, ANSYS CFX.

Experimental Test

The experimental test was conducted in a tank test belonging to ITS, with the following parameters: length (L) of 50m, breadth (B) of 3m, depth (H) of 2m, maximum draft (T) of 1.8m and maximum speed of carriage at 4.0 m/s. Table 1 displays the parameters, body plan and setting of the model. They are represented in Figures 1 and 2, respectively. The test was conducted at various speeds (and Froude numbers), with space-to-length ratios or clearances (S/L) as shown in Table 2.



(a) (b)

Figure 1: Body Plan of Model: Mainhull (a) and Sidehull (b)

Table 1: Principle Particulars of Trimaran Vessel and Model

Dimensi Partikular		Trimaran Vessel	Model
LOA	M	74.14	1.2525
LPP	M	72.09	1.2178
$B_{Mainhull}$	M	9.91	0.1675
$B_{Sidehull}$	M	5.71	0.0965
B (S/L = 0.2)	M	34.55	0.5836
B (S/L = 0.3)	M	48.98	0.8274
B (S/L = 0.4)	M	63.38	1.0707
B (S/L = 0.5)	M	77.94	1.3166
H	M	7.16	0.1210
T	M	3.951	0.0667
WSA	m^2	1367.93	0.3904
Displacement	Ton	1440.00	0.006942

Table 2: Configuration and Various Speed of Test

Froude Numbers (Fr)	Type of Ship	Clearance (S/L)
0.15, 0.17, 0.19, 0.21, 0.23, 0.25, 0.27	Trimaran	0.2, 0.3, 0.4, 0.5

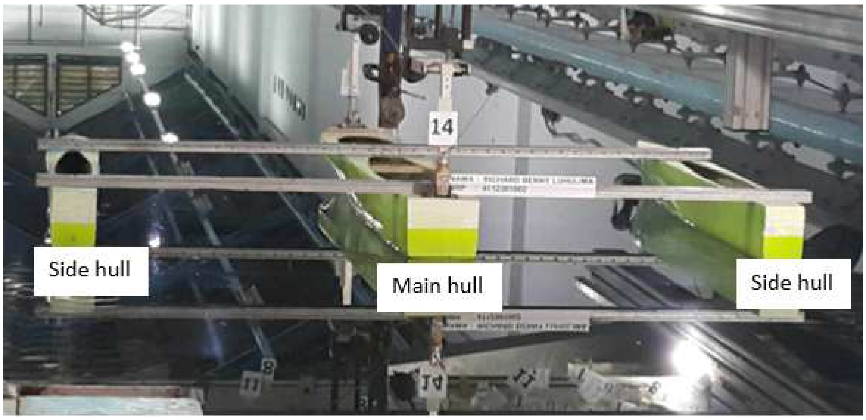


Figure 2: Setting of Trimaran Model in the Towing Tank

CFD Analysis

Computational Fluid Dynamics (CFD) technique has, varied degree of complexity. It is used to predict various resistance components. Potential code may be applied to derive the pressure resistance due to inviscid flow characteristics (wave pattern resistance). The boundary layer intergral method, helps to determine the boundary layer growth. This method is usually applied in areas where separation and circulation do not occur. This method helps to draw perception regarding the pressure form drag. Full Reynolds-Averaged Navier-Stokes (RANS) codes, help to predict flow when separation and circulation occur. Therefore, this method holds good potential for estimating form factor and possible scale effect. Nevertheless, it must be noted that, these methods are extremelly computationally intensive, particularly for the computation of high Reynolds number flow.

CFD analysis helped to determine the flow movement phenomenon. This causes decrease of the increase of total resistance. Resistance investigations have been widely conducted, especially by Utama (1999), Utama and Molland (2001), Subramanian et al (2006), Siqueira et al (2007), Deng et al (2010), and Jamaluddin et al (2013).

The boundary conditions were set according to Utama (1999), Ahmed and Soares (2009). The inlet boundary, located at 1.5L upstream from the ship, is defined as a uniform flow, with velocity equalling the ship velocity. The outlet boundary, at a location of 4L downstream from the ship, is pressure equivalent to the undisturbed pressure, which ensures there are no upstream propagation of disturbances. Furthermore, the distance between both sides of boundary is 1.5L and the distance between top and bottom boundaries is set at 2.5L. The boundary condition at the hull surface is defined as, no-slip boundary. The boundary condition at the (parallel to the flow direction) horizontal and vertical walls, bounding the flow domain is as free-slip boundary. Figure 3 provides the details. The investigation was conducted without and with free surface effect, to quantify the contribution of wave resistance to the total resistance.

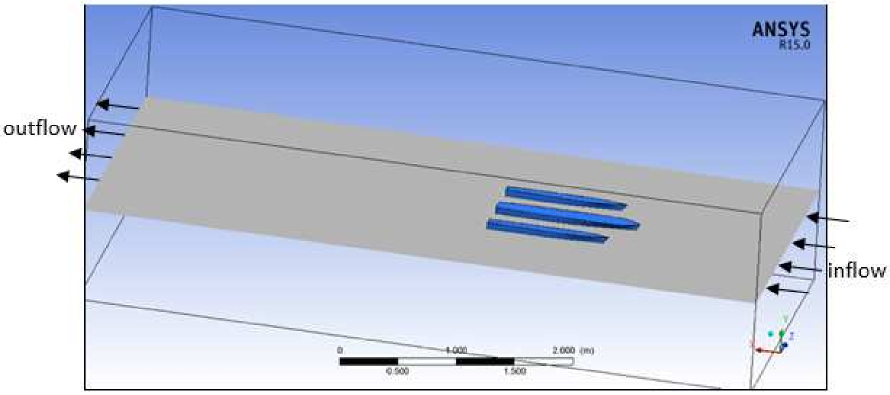


Figure 3: Setting of Model and Boundary Conditions in CFD Domain

The choice of turbulence models may determine the type of result obtained and is, therefore, significant in the simulation of wake fields. The turbulence model used in this study was the SST (Shear Stress Transport) model, developed by Menter (1993 and 1994). The SST model has been used and validated by several researchers, including Bardina et al (1997) and Swennberg (2000), with successful results. The viscous flow field is solved using RANS (Reynolds Averaged Navier-Stokes) solver, implemented in ANSYS CFX.

RESULTS AND DISCUSSIONS

Calibration Criteria of the Experimental Work

The International Towing Tank Conference (ITTC) standard emphasizes the importance of calibration of the load cell. This ensures that, the load cell provides the real and correct results of measurement (ITTC, 1978). The calibration test was performed, using a load cell of 2 kg. The load was measured and calibrated prior to the test. The results were analysed using computer data analysis system. An error less than 5% (ITTC, 1978) was accepted. Therefore, if computer analysis showed an error of measurement less than 5%, then the load cell was further used for tank test experiment. If not, the calibration was repeated.

Grid Independence and Convergence Criterion

Grid independence study was performed to ensure that, the total resistance conformed with the convergence and grid-independence criteria. The convergence criterion was 10^{-5}, which was determined by momentum residual, according to Dinham et al (2008). Grid independence is defined as the difference between the two subsequent calculated ship resistances, which must always be less than 2% (Anderson, 1995). The ship resistance of the latter was calculated using a cells (elements), of approximately twice the number of that in the former. Table 3 illustrates a summary of ship resistance calculations, using different number of elements. In this study, 1,583,000 (or approximately 1.6 million) elements in the simulation, satisfies the grid-independence criterion. Figure 4 depicts a graphical representation of the grid independence study.

Table 3: Grid Independence Study

Number of Grid	50,822	102,620	202,162	408,291	812,738	1,582,580	3,075,830
Resistance (N)	4.065	3.368	2.884	2.563	2.360	2.262	2.219
Percentage of Difference (%)		20.684	16.793	12.546	8.581	4.332	1.938

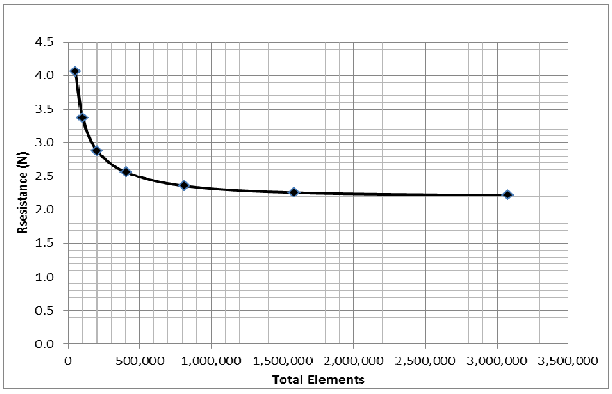


Figure 4: Grid Independence

Tables 4 presents a summary of the experimental and CFD results, corresponding to figures 5 to 8. These figures highlight the magnitude of each resistance component at differing speeds (Froude numbers) and separation to length ratio (S/L).

Table 4: Total Resistance Coefficient Estimation

Fr	**Total Resistance Coefficient**									
	Trimaran Independent Hull (x 10^{-3})		**S/L = 0.2 (x 10^{-3})**		**S/L = 0.3 (x 10^{-3})**		**S/L = 0.4 (x 10^{-3})**		**S/L = 0.5 (x 10^{-3})**	
	CFD	**Expt.**	**CFD**	**Expt.**	**CFD**	**Expt.**	**CFD**	**Expt.**	**CFD**	**Expt.**
0.15	4.170	4.207	4.491	4.257	4.391	4.248	4.291	4.228	4.120	4.218
0.17	4.158	4.358	4.848	5.169	4.647	5.108	4.458	4.779	4.162	4.367
0.19	4.423	4.623	5.258	5.375	5.003	5.246	4.803	5.025	4.433	4.697
0.21	5.035	5.135	5.965	5.862	5.446	5.605	5.265	5.456	5.135	5.162
0.23	5.608	5.708	6.295	6.557	6.195	6.288	5.947	5.977	5.618	5.777
0.25	5.801	5.880	6.443	6.681	6.393	6.581	6.293	6.312	5.911	6.058
0.27	5.765	5.865	6.653	6.792	6.533	6.728	6.333	6.346	5.825	6.092

Figures 5 to 8, depict the experimental and CFD results of the total resistance coefficients. Results from both approaches were similar and in good agreement with each other. The average difference in the result with both methods, was about 5%. Experimentally, the values obtained were always rather higher than using CFD calculation. This was explained, resulting from the quality of model used, as it could not be perfectly the same as the model built in design generator software, such as AutoCAD and Maxsurf (Utama, 1999). Another explanation suggested was, the surface quality of the experimental model, which was never 100% smooth and, therefore, the debris and notches could increase the total resistance of the model (Dryden, 1950).

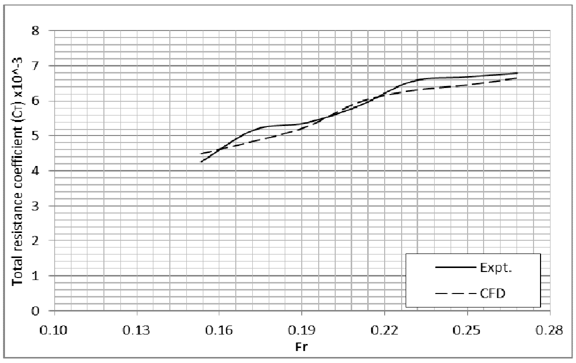


Figure 5: Total Resistance Coefficient at S/L = 0.2

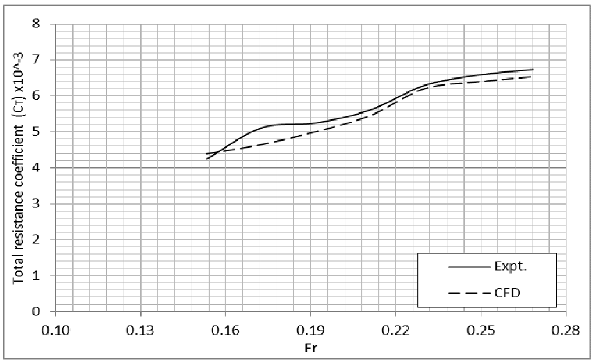


Figure 6: Total Resistance Coefficient at S/L = 0.3

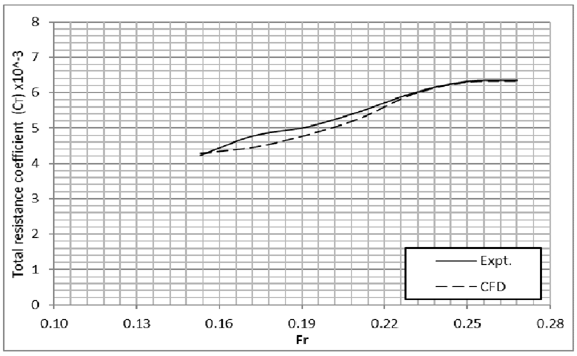


Figure 7: Total Resistance Coefficient at S/L = 0.4

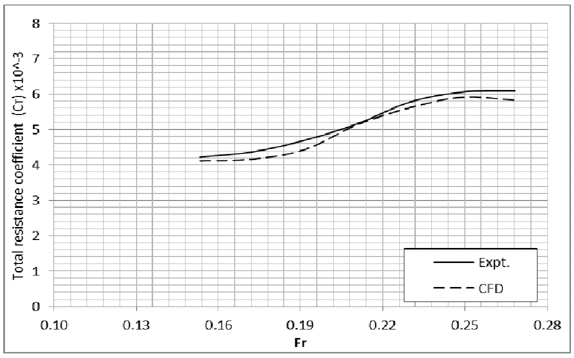


Figure 8: Total Resistance Coefficient at S/L = 0.5

Table 5: Total Resistance Interferensi

Fr	Total Resistance If							
	S/L = 0.2 (x 10^{-3})		S/L = 0.3 (x 10^{-3})		S/L = 0.4 (x 10^{-3})		S/L = 0.5 (x 10^{-3})	
	CFD	Expt.	CFD	Expt.	CFD	Expt.	CFD	Expt.
0.15	1.077	1.012	1.053	1.010	1.029	1.005	0.988	1.003
0.17	1.166	1.186	1.118	1.172	1.072	1.097	1.001	1.002
0.19	1.189	1.163	1.131	1.135	1.086	1.087	1.002	1.016
0.21	1.185	1.142	1.082	1.091	1.046	1.062	1.020	1.005
0.23	1.123	1.149	1.105	1.102	1.061	1.047	1.002	1.012
0.25	1.111	1.136	1.102	1.119	1.085	1.074	1.019	1.030
0.27	1.154	1.158	1.133	1.147	1.098	1.082	1.010	1.039

CONCLUSIONS

The applications of experimental and CFD approaches, to determine the breakdown and analysis of trimaran resistance were presented in this study. Both methods meet the calibration procedure, for the experimental study and grid-independence criteria, for the CFD investigation.

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